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RESEARCH MEMORANDUM

LIMITED INVESTIGATION OF NOISE SUPPRESSION BY INJECTION OF WATER INTO EXHAUST OF AFTERBURNING JET ENGINE

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NATIONAL ADVISORY COMMITTEE
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LIMITED INVESTIGATION OF NOISE SUPPRESSION BY INJECTION OF WATER INTO EXHAUST OF AFTERBURNING JET ENGINE

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SUMMARY

The injection of water into the jet-engine exhaust has been suggested as a possible means for suppressing noise during static ground operation of jet engines. The present investigation has been conducted with a simple rig which pumps high-pressure water into the exhaust of an afterburning jet engine. Tape recordings of the noise have been made at stations about the engine, with and without water injected into the exhaust stream, to determine the effect of the water on the noise output of the jet engine.

Analysis of the tape recordings shows that a maximum attenuation of approximately 2 to 6 decibels in overall sound-pressure level was achieved with application of water to the jet exhaust. Although this reduction is not considered sufficient to justify use of water as a muffler, it is important to note that the reduction was achieved by reductions of as much as 10 decibels in the range of frequencies below 800 cps. Atmospheric attenuation is least in this range, and it is, therefore, a frequency range important to the neighboring community.

INTRODUCTION

The noise emitted during the ground operation of jet engines, aside from being annoying to the surrounding community, is a hazard to the necessary operational personnel in the immediate vicinity of the airplane. Several types of noise suppression are available at the present time. However, most of these are cumbersome to fit to airplanes and have high initial costs. One type which would not have these disadvantages, but on which little information is readily available, involves the injection of water into the exhaust.

The investigation reported herein was an exploratory one conducted with a simple rig designed to pump water into the hot exhaust stream. Since the noise of a jet engine varies with the jet exhaust-stream velocity to the eighth power, any means of reducing the jet exhaust velocity should reduce the noise level. Water properly injected into the hot-velocity stream should reduce the velocity of the stream both by cooling the gases and by reason of the energy required to accelerate the water mass. A noise suppressor of this type would be inexpensive and easy to fit to an airplane, would not interfere with normal engine operation, and would have no reaction from the jet blast that would require heavy anchoring.

APPARATUS AND PROCEDURE

Water Rig

The water manifold rig is shown in figure 1 operating behind the airplane used in the present investigation. A drawing giving the dimensions of the rig and the two sizes of nozzles used is shown as figure 2. The nozzle design was dictated by the results of reference 1.

With a setup of six 1/2-inch-diameter nozzles and six 1/4-inch-diameter nozzles spaced alternately about the circumference of the rig, 650 gallons of water per minute were pumped into the jet stream at a pressure of 160 pounds per square inch gage. This nozzle setup was designed to allow penetration into the core of the jet from the six 1/2-inch nozzles and some coverage of the outer perimeter from the six 1/4-inch nozzles. With a setup of twelve 1/2-inch-diameter nozzles equally spaced about the rig, 880 gallons of water per minute were pumped into the jet stream at a pressure of 100 pounds per square inch gage. This nozzle setup was designed to allow the maximum amount of water to operate in the hot core section of the jet exhaust.

The water used for the investigation was supplied from a 4-inch fire hydrant. Pressure was obtained by means of a fire pumper. Three 4-inch-diameter flexible hoses, each 50 feet long, placed in parallel, were used from the pumper to the rig to reduce the line losses.

Due to the protrusion of the drogue chute housing above and rearward of the tailpipe, the water rig could not be placed closer than 1 tailpipe diameter from the exit. The present investigation was made with the rig at this distance from the tailpipe.

Jet Engine

The jet engine used produces 8,000 pounds of thrust with afterburner. The rated tailpipe temperature is approximately 2,900° F and the exit jet velocity is approximately 2,700 feet per second. The exit diameter of the afterburner tailpipe is 27 inches.

Test Procedure

Figure 3 shows the relative positions of the equipment used, the buildings in the vicinity, and the stations where sound recordings were made. Recordings at each of the stations began as the afterburner was placed in operation, and after a short time water was turned into the rig. As this procedure required less than 1 minute, the samples of the recording before and after the application of water enable comparisons of the noise to be made at essentially the same engine operating conditions.

Sound Recording and Analyzing Equipment

The recording and analyzing equipment yields sound levels to within ±1 decibel from 100 to 15,000 cps. Below 100 cps the response corrections applied to the spectra become increasingly inaccurate. Also, examination of results made with a 300-cps band-width filter showed that the water had no effect on the spectra above 800 cps. For these reasons, data are presented in detail only in the range of 100 to 1,000 cps. In this range a 30-cps band-width filter was used and the levels were then corrected to a 1-cps band width for presentation in this report.

More complete information on the equipment is given in the appendix.

RESULTS

Overall Sound-Pressure Levels

The overall sound-pressure levels obtained from the tape recordings are shown in figure 4. For this comparison all levels have been corrected to a 100-foot distance by use of the inverse square law. At each station, with a given nozzle setup, the water-on and water-off noise levels are for identical engine operating conditions. However, for each station, each nozzle setup requires a separate engine run. The slight differences in engine operating conditions that result are responsible for the difference in sound levels at the same station for operating conditions that are apparently the same.

Figure 4 shows that the addition of water caused a reduction of about 6 decibels in the overall sound-pressure level in the direction of maximum noise level, station 1^R (150°). At stations farther forward smaller reductions in noise were measured. In general, the difference in sound level caused by the water is the same for both the nozzle configurations used.

Frequency Spectra of the Noise

The frequency spectra obtained at several stations, both with and without water applied, are shown in figure 5. The comparison shows that the reduction in overall noise levels was afforded by reductions in the noise levels of the spectra only below 800 cps. Although a range up to 15,000 cps was examined, the results are presented only up to 1,200 cps because no significant changes due to water injection were found above this value.

DISCUSSION

Although the reductions in overall sound-pressure level are not considered great, it is important to point out that the reductions were achieved by significant reductions (up to 10 decibels) in the frequency range below 800 cycles per second, where usual atmospheric attenuations are the least. Therefore, such a reduction would be important to the neighboring community.

The present limited tests were conducted with the water rig placed approximately 1 jet diameter behind the exit. For both nozzle setups visual and photographic evidence, as shown in figure 1, indicates that the water penetrated the core of the jet stream roughly 1 jet diameter downstream of the rig. Also, the photographs show that the rig gave poor water coverage of the outer area of the jet.

It seems likely that both placement of the rig closer to the jet exhaust exit and a more effective coverage of the outer area of the exhaust would reduce the noise further. Closer placement of the rig to the jet is possible without significant effects upon the engine operation. Tests conducted with screen-type mufflers (ref. 2) showed little effect upon the engine operation. The water spray would produce even less effect. More complete coverage of the entire cross section of the exhaust could be achieved by use of a fine spray as near the exit as possible, followed by coarser and coarser jets until full penetration of the exhaust is achieved.

In addition, the finer spray at the exit will present more water surface to the hot exhaust gases. Reference 3 presents a study of vaporization of small water droplets which shows that the rate of heat transfer varies directly with the surface area of the droplets. The study also shows that an additional factor, the masking effects of surrounding water droplets, places a practical limit on the amount of water used. This result implies that there may be an optimum amount of water to use, which may have been exceeded in the present test.

CONCLUDING REMARKS

A preliminary investigation of the effect of injection of up to 880 gallons of water per minute on the noise production of an afterburning jet engine producing 8,000 pounds of thrust showed a reduction of 2 to 6 decibels in overall sound-pressure level in the direction of maximum noise radiation. It was further noted that the reduction in overall sound pressure was achieved by significant reductions (up to 10 decibels) in the range of frequencies below 800 cps, a region where the attenuation due to atmospheric losses is negligible.

The limited range of this test did not allow the investigation of the effects of such possibly significant parameters as the distance of the rig from the jet exit, pressure and quantity of water, and distribution of the water to the jet.

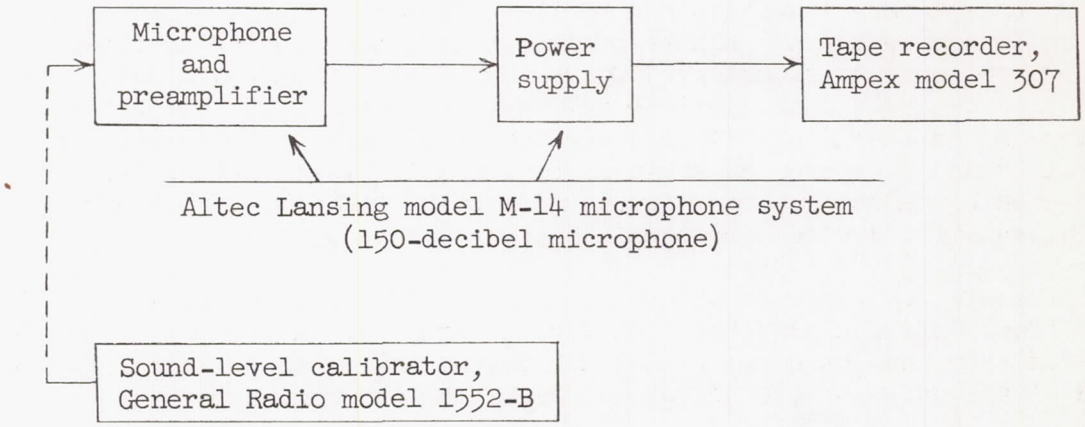
Langley Aeronautical Laboratory,
National Advisory Committee for Aeronautics,
Langley Field, Va., Nov. 15, 1957.

APPENDIX

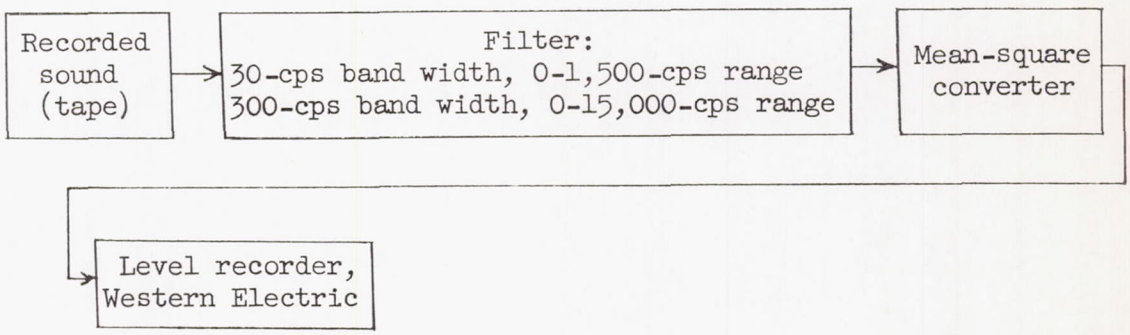
RECORDING AND ANALYZING SYSTEMS

The recording equipment and the analyzing equipment each had an overall error of approximately $\pm \frac{1}{2}$ decibel.

Recording Equipment



Analyzing Equipment

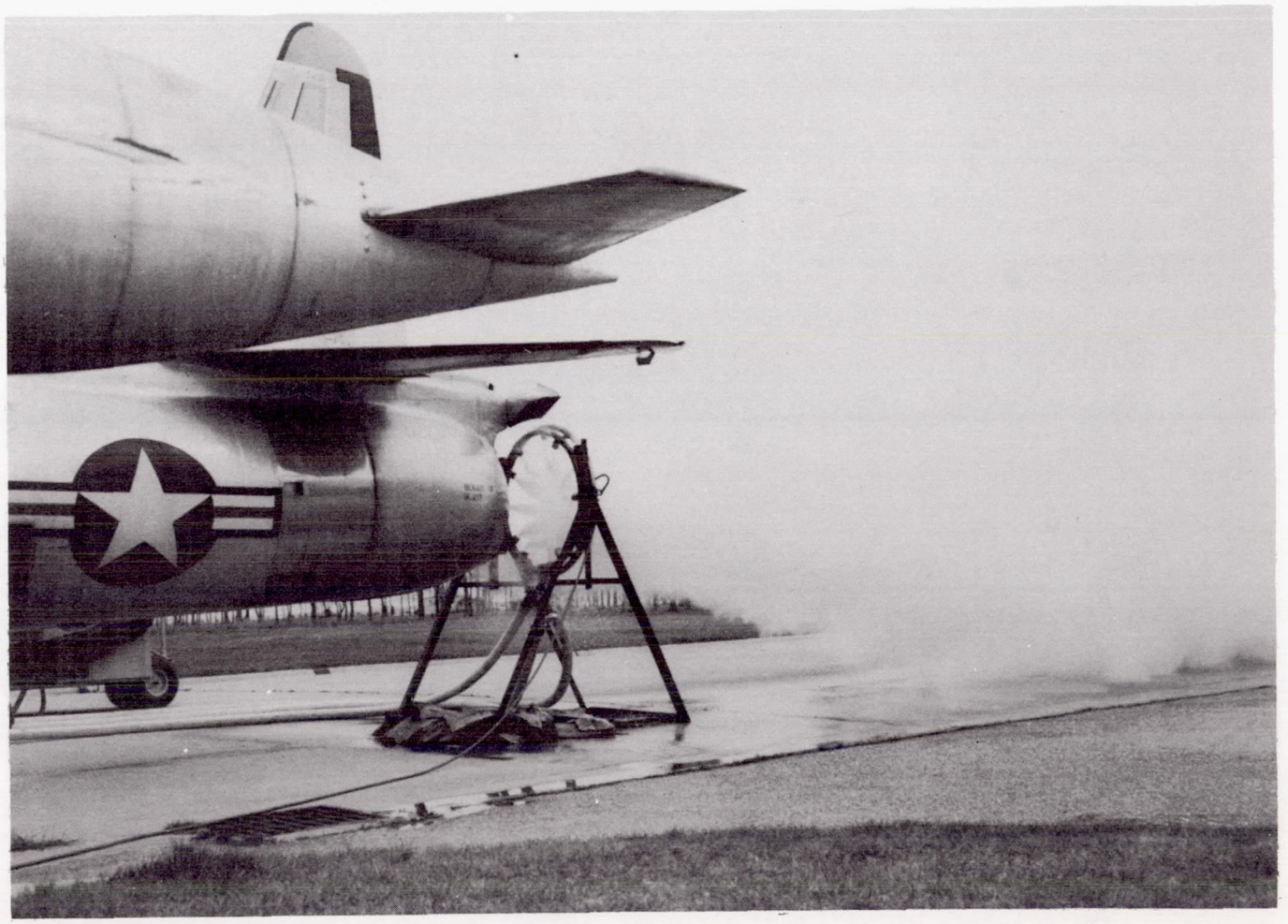


REFERENCES

1. Chelko, Louis J.: Penetration of Liquid Jets Into a High-Velocity Air Stream. NACA RM E50F21, 1950.

2. Coles, Willard D., and North, Warren J.: Screen-Type Noise Reduction Devices for Ground Running of Turbojet Engines. NACA TN 4033, 1957.

3. Imbrie, William: A Study of Vaporization of Small Water Droplets Produced by a High Pressure Injection System. M. Mech. E. Thesis, Rensselaer Polytechnic Inst., 1951.



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Figure 1.- Water manifold rig in operation behind the test airplane. This nozzle setup, one of two used, consists of six 1/2-inch-diameter nozzles and six 1/4-inch-diameter nozzles.

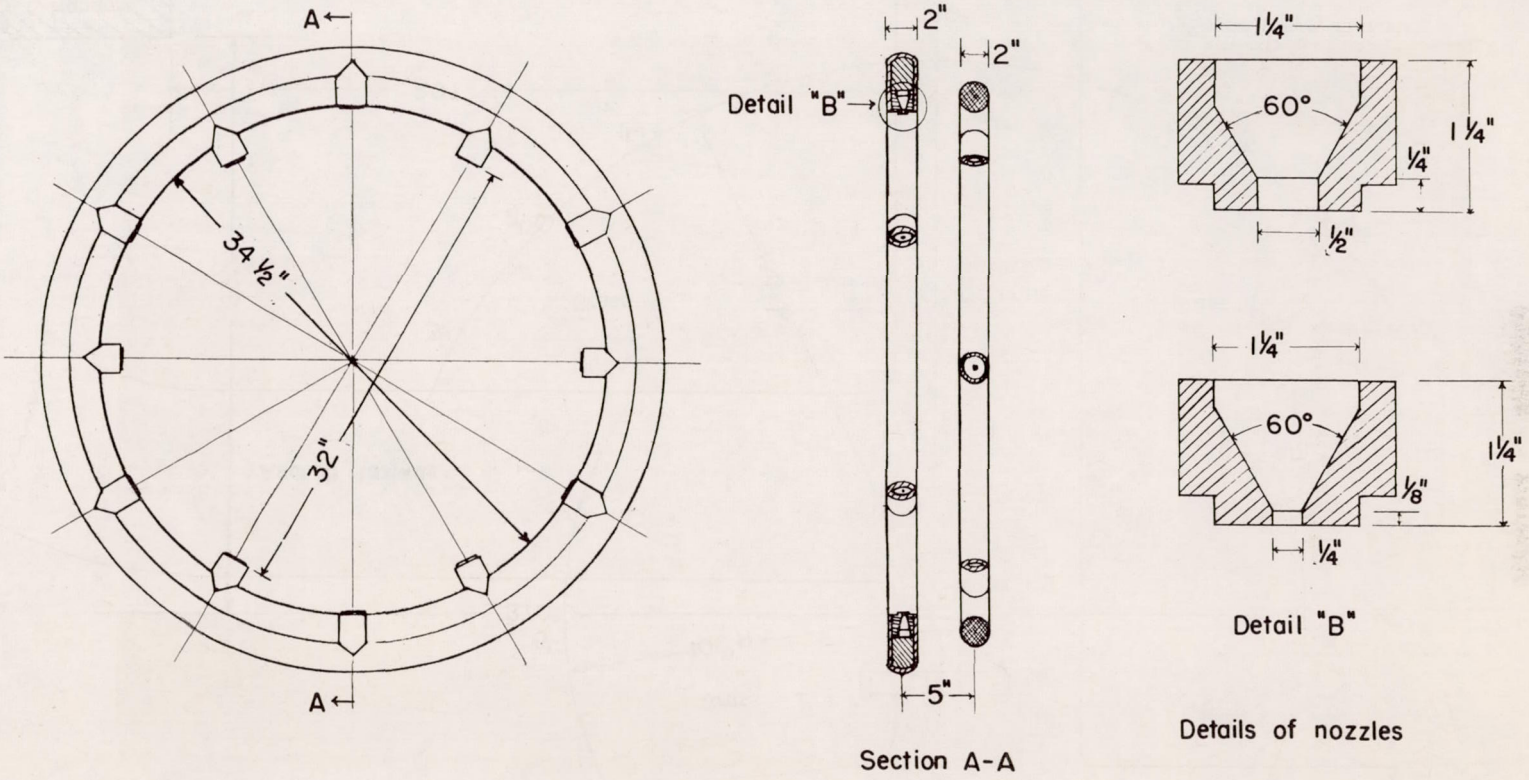


Figure 2.- Dimensions and arrangement of the water manifold rig and nozzles used.

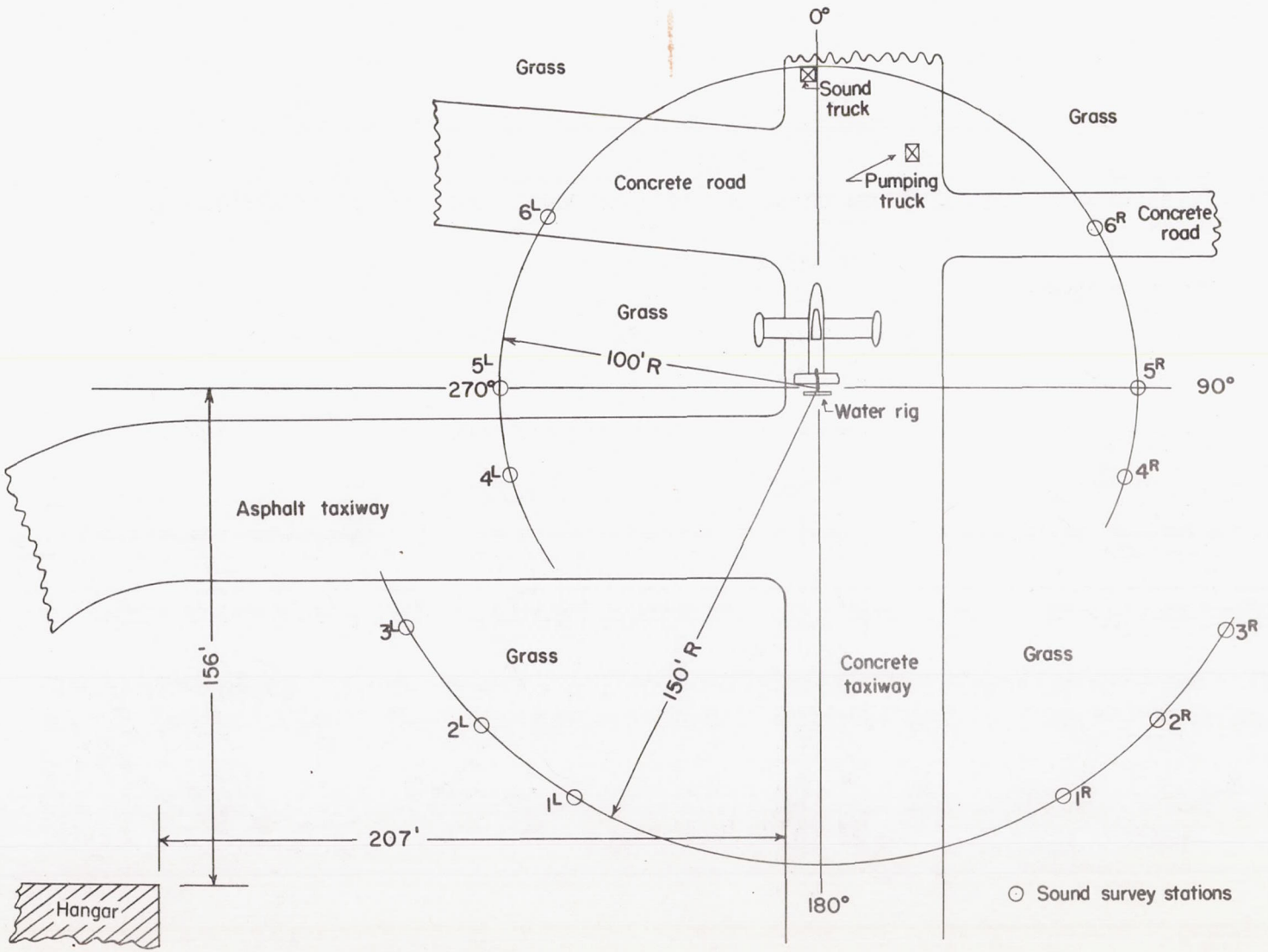


Figure 3.- Relative positions of the sound survey stations, equipment used, and buildings in the vicinity during the investigation.

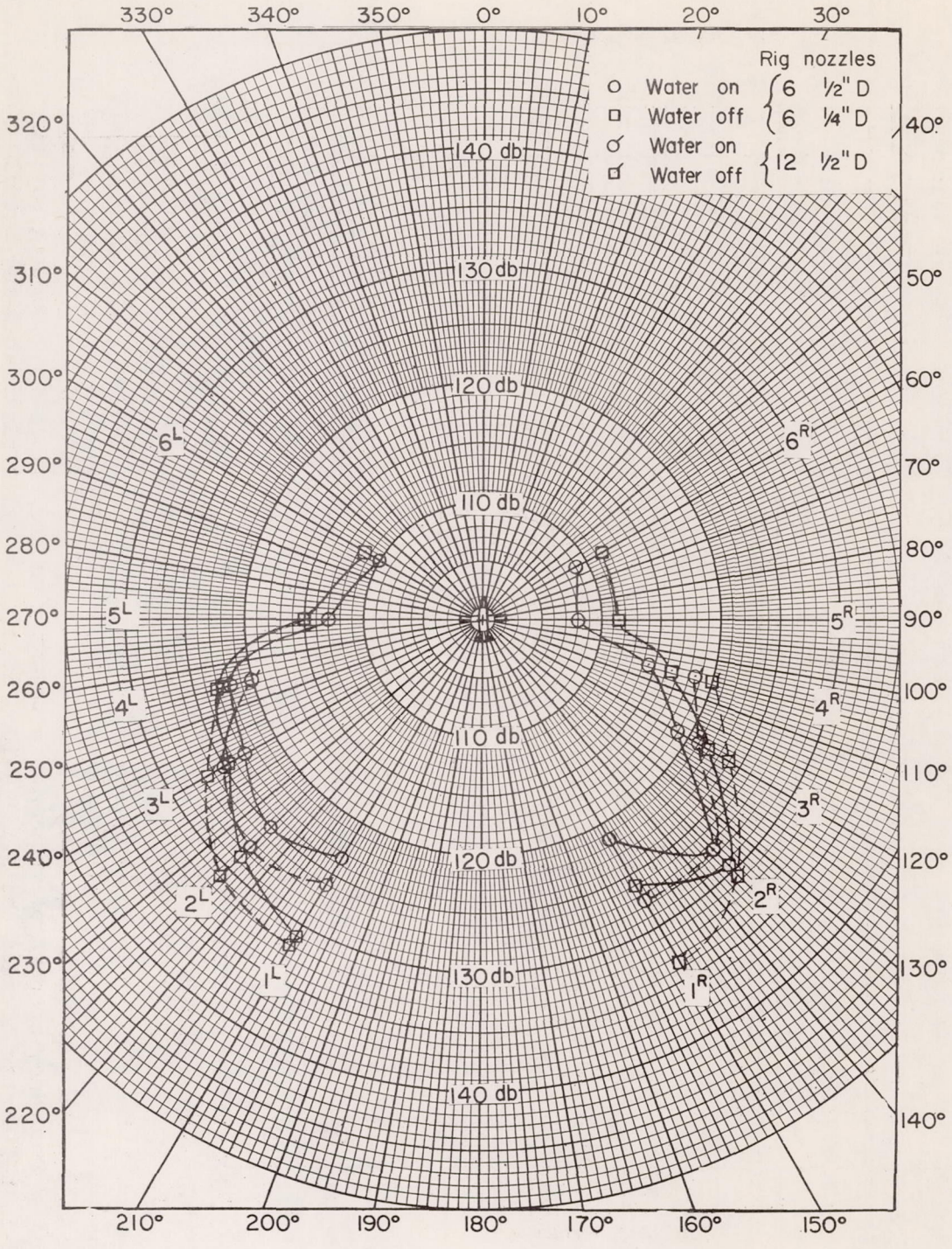
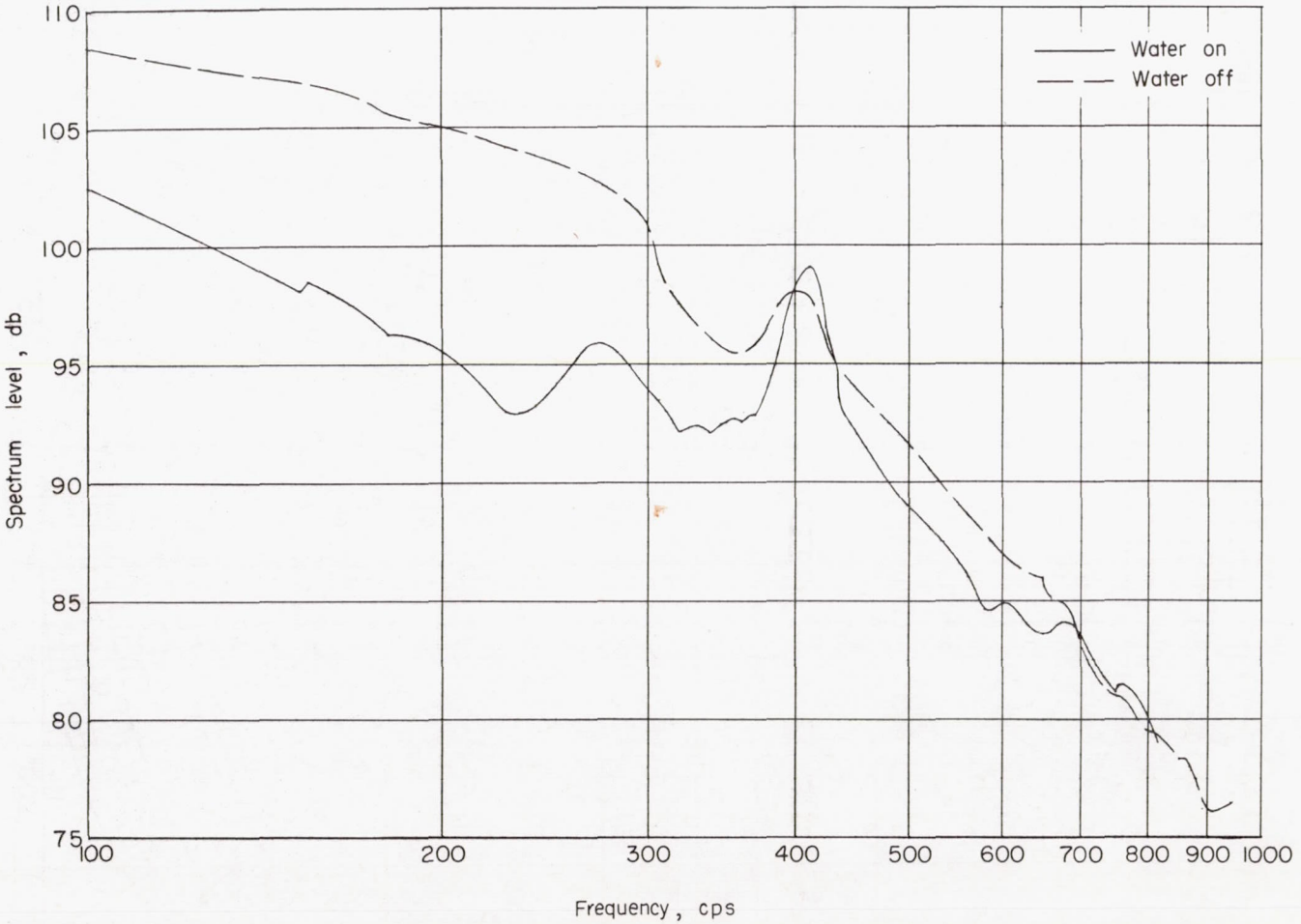
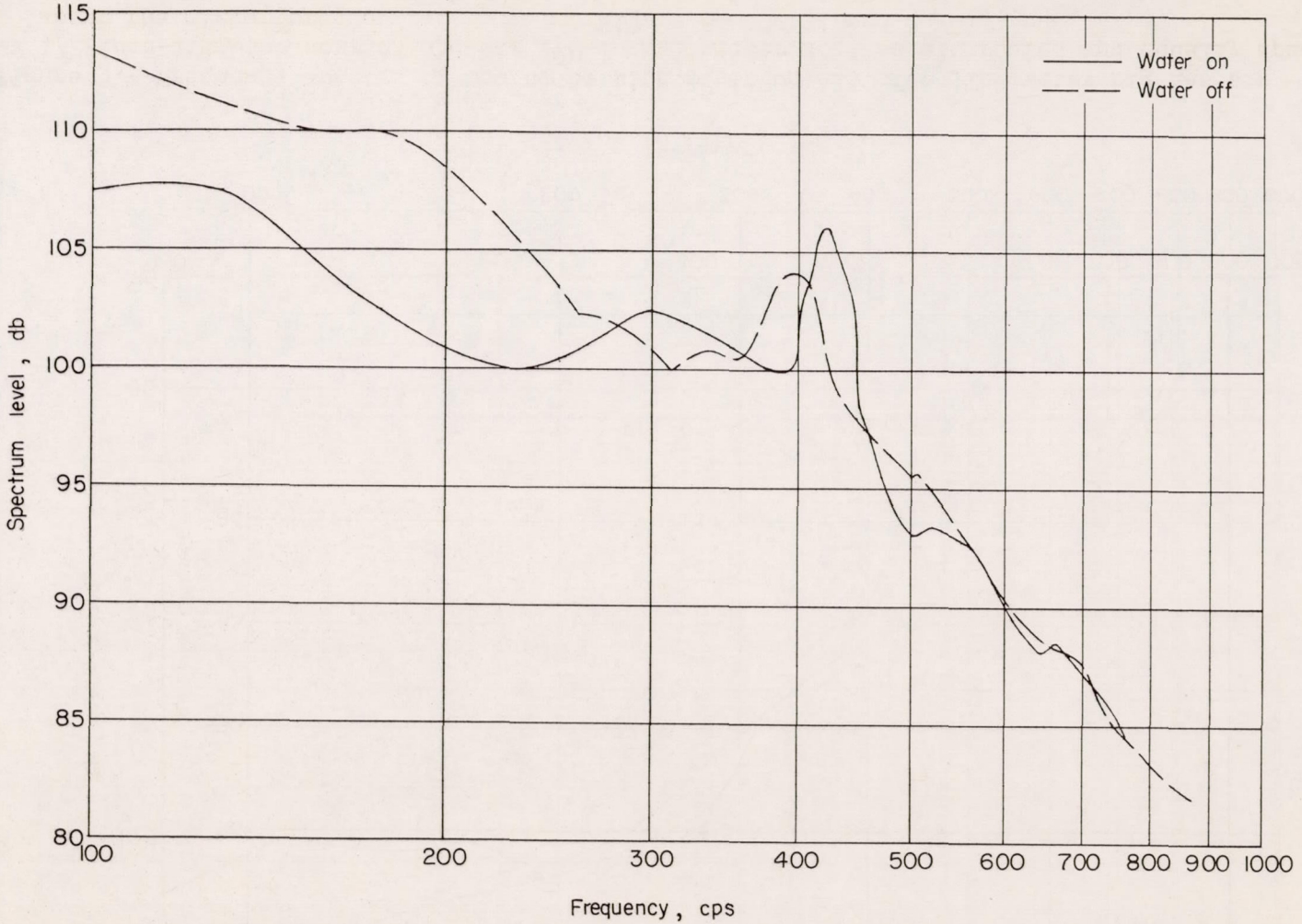


Figure 4.- Overall sound-pressure levels, corrected to a 100-foot distance.



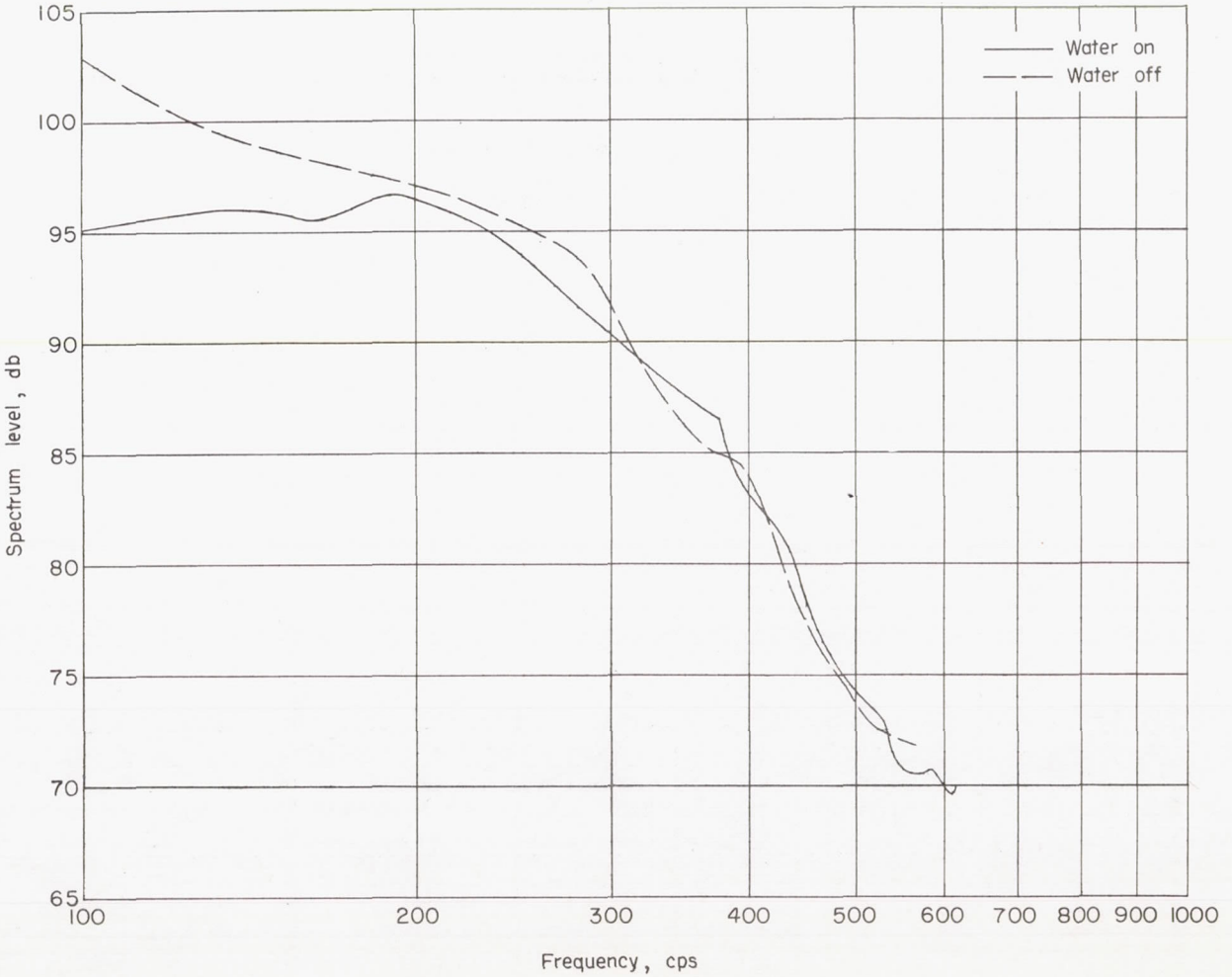
(a) Station 1^R (150°; 150 feet).

Figure 5.- Frequency spectra of the noise with water on and off. The water rig has six 1/2-inch-diameter nozzles and six 1/4-inch-diameter nozzles alternated and equally spaced about the circumference.



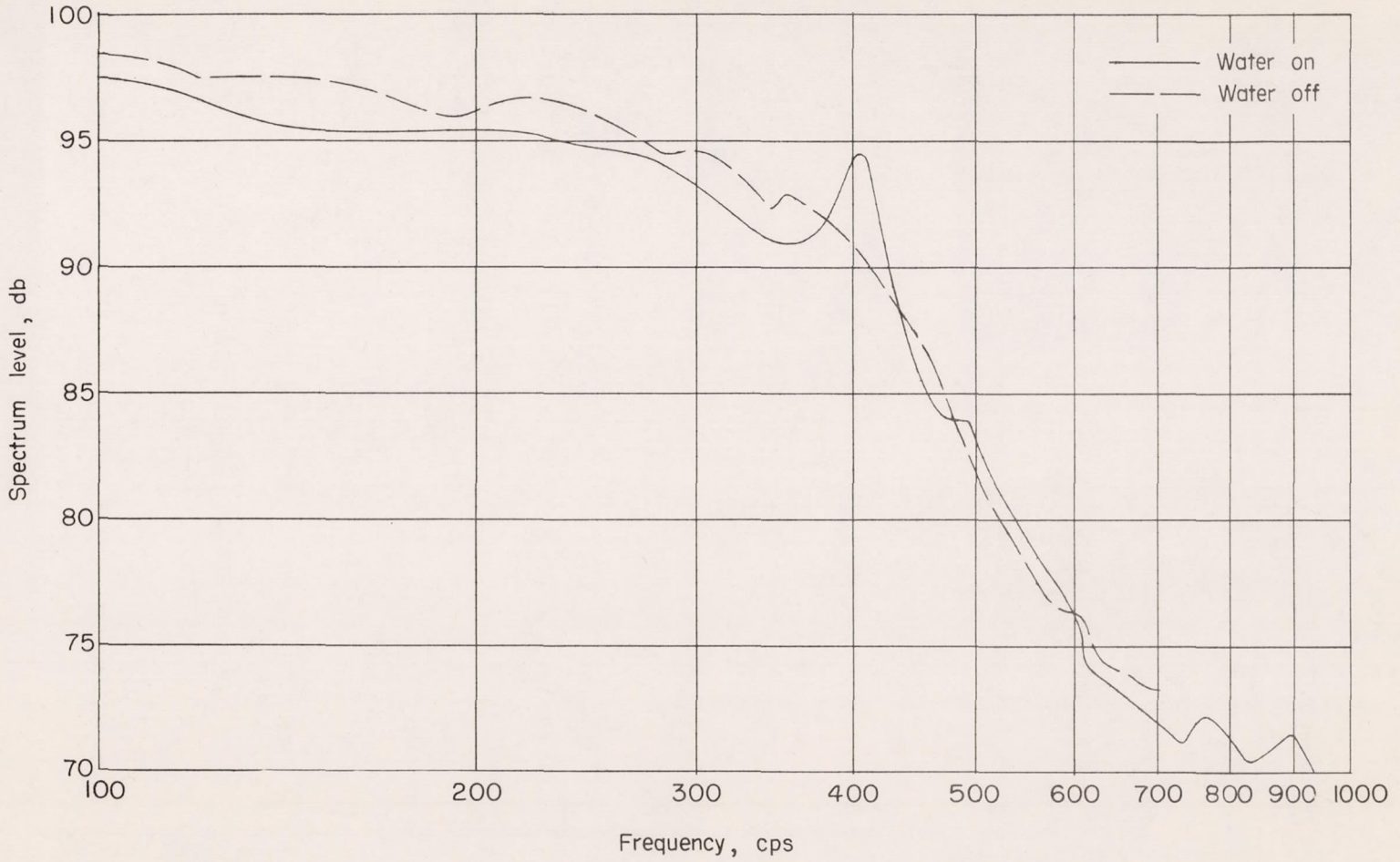
(b) Station 2^R (135°; 150 feet).

Figure 5.- Continued.



(c) Station 3^R (120°; 150 feet).

Figure 5.- Continued.



(d) Station 4^R (105^o; 100 feet).

Figure 5.- Concluded.

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